TECHNOLOGIES FOR A LONG DURATION LANDER ON THE SURFACE OF VENUS

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Outline

- Overview
- Venus Mission Planning Evolution
- Strawman Technology Demonstration Missions
  - Venus Flagship Mission
  - Venus Pathfinder Mission # 1
  - Venus Pathfinder Mission # 2
- Conclusions

Overview

- This presentation summarizes the work done under the NASA GRC sponsored effort to look at technologies needed for a long duration Venus lander
- It also provides some of the engineering detail behind a paper presented last year at IPPW8 by Ralph Lorenz

  Venus Pathfinder – A Compact Long-Lived Lander

- Significant technology development is needed to get a viable proposal ready for a long-term Venus lander in the next few years, but those technologies need to be focused on the desired mission
- There is not one technology that will enable all potential missions but rather different technologies for different types of mission
- Simpler technologies can be available earlier than the more complicated ones

Strawman Missions

- To provide a basis for the technology development discussion, the study looked at three potential Venus lander missions

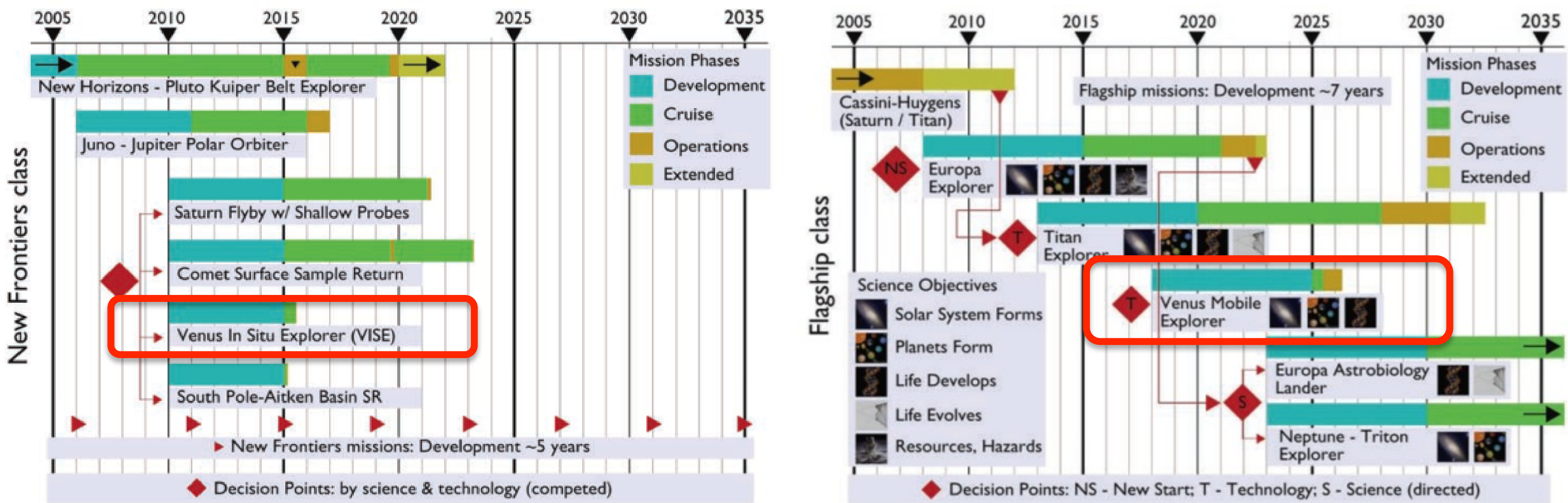
1. **A long term lander defined in the Mission Architecture Enhancements section of the 2009 Venus Flagship Study Report.**
   - 400 W electrical load
   - 700 W thermal load

2. **A 50-200 day mission for a compact lander focused on meteorology and seismicity based on the IPPW8 Lorenz paper**
   - 10 W electrical load
   - 70 W thermal load

3. **A 15 day all high-temperature lander**
   - 1 W electrical load
   - Primary battery powered
   - Ambient temperature operation

NASA 2006 Solar Exploration System Roadmap

- The NASA 2006 Solar Exploration System Roadmap recommended an aggressive exploration of Venus



- Farther out there would be a Venus Sample return
- Early mission demonstrated technologies in preparation for Flagship mission
- Mobility and duration were critical technologies to be demonstrated
- Environmental challenges will drive technology investment

NRC 2011 Decadal Survey

- The NRC 2011 Decadal Survey lists VISE as a New Frontiers mission candidate
- A Venus Climate Mission is listed as one of the five Flagship candidate missions
  - The mission architecture includes
    - a carrier spacecraft
    - a balloon system
    - a mini-probe
    - two drops sondes
- The report notes that many crucial analyses of Venus cannot be obtained from orbit, but that sample return appears beyond the scope of current technology
- Both roadmap documents note the technical challenges of a long-term lander are limiting its inclusion in potential missions

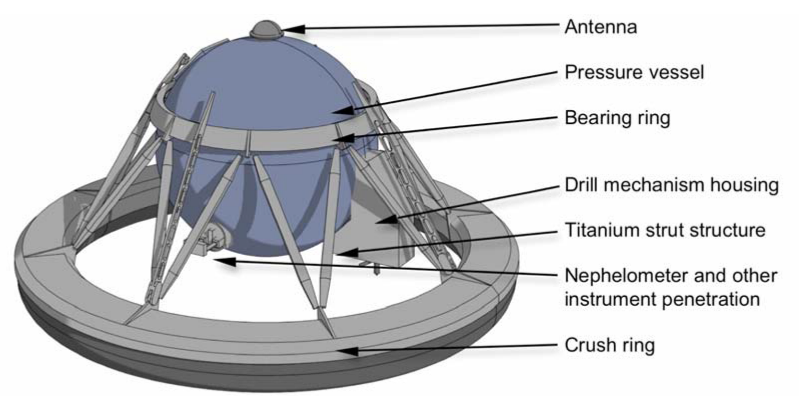
Venus Flagship Mission Study – Design Reference Mission

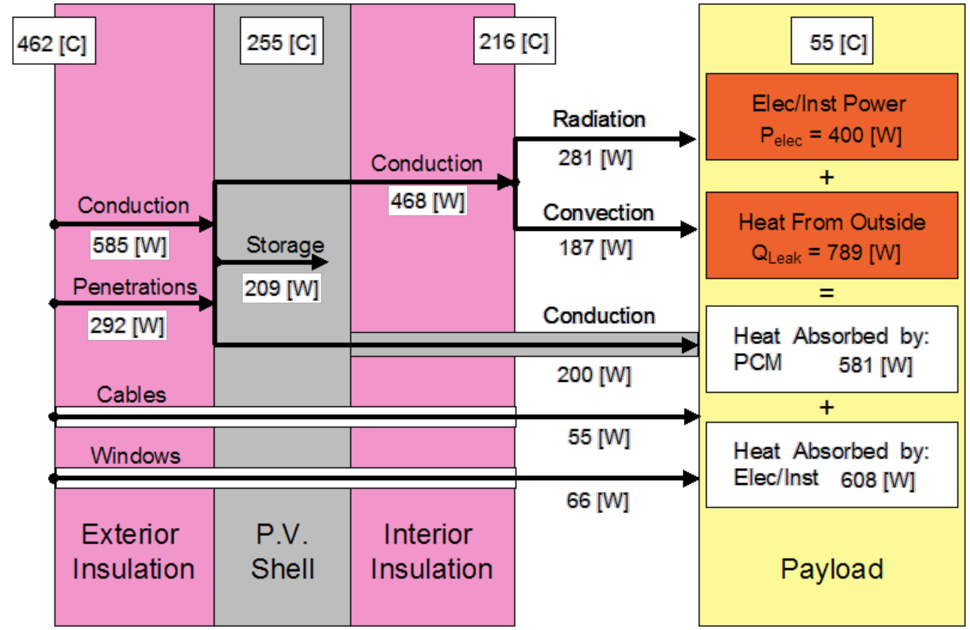
- **2009 Venus Flagship study**
  - **Target launch date 2020 to 2025**
  - **Access to earlier technology validation experiments to enable or enhance mission**
  - **Show path to future Venus Surface Sample return concept**

- **Architecture elements**
  - **Orbiter** — **Relay support**
  - **Entry system**
    - **1969 kg each**
    - **Carbon-Phenolic TPS, 2.65 m dia**
  - **Short lived Lander** — **5 hours, may include long lived components**
    - **686 kg; power 492 W Descent with telecom, 729 W surface ops with telecom**
    - **0.9 m diameter shell (1 cm wall internal, 5 cm external insulation)**
    - **Power 6 kW hrs, battery mass 12.6 kg**
    - **Penetrations: windows, feed-thrus, tubes for pressure sampling**

Venus Flagship Mission Study – Enhanced Mission

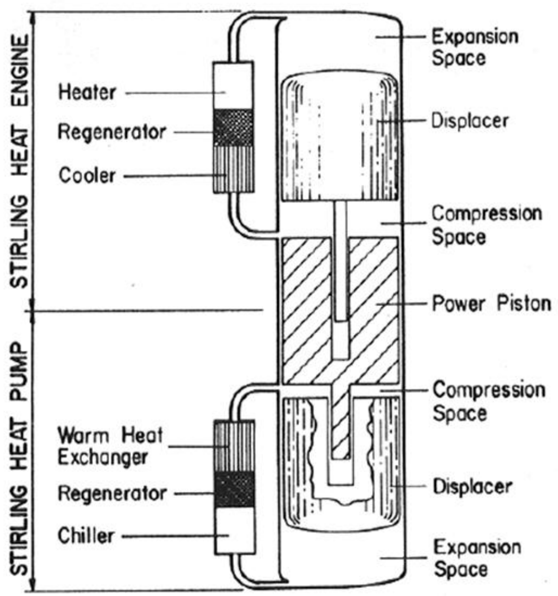
- The first design case is the lander defined as part of the 2009 VFM Design Reference Mission
- The Mission Architecture Enhancement section lists the benefits of a long-lived, refrigerated Lander with a near full compliment of DRM Lander capabilities operating for months



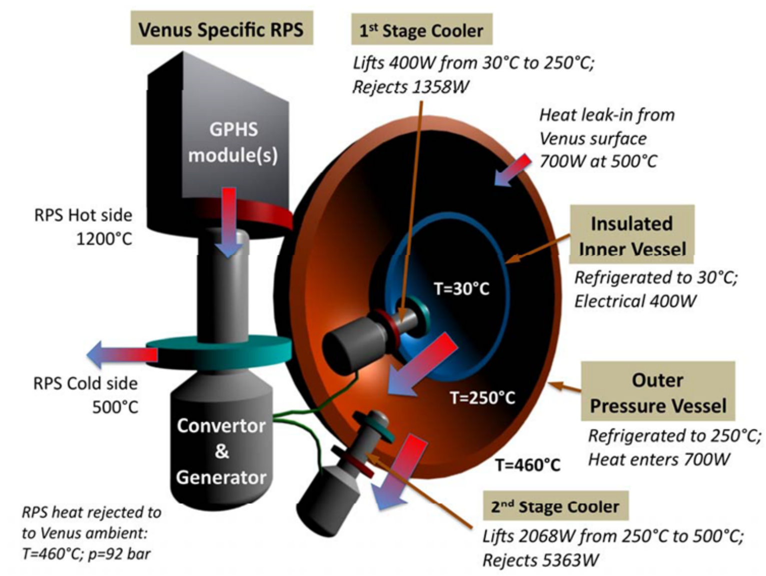


Venus Flagship Mission Study – Heat Balance

- One technology enabling a long-lived mission is a Stirling Duplex engine that provides cooling to a protected enclosure
- One, two, and three stage systems were looked at that required between 54 and 94 GPHS bricks



Penswick, L. B., and I. Urieli, Duplex Stirling Machines, 19th Annual Intersociety Energy Conversion Engineering Conference, San Francisco, CA, August 1984.



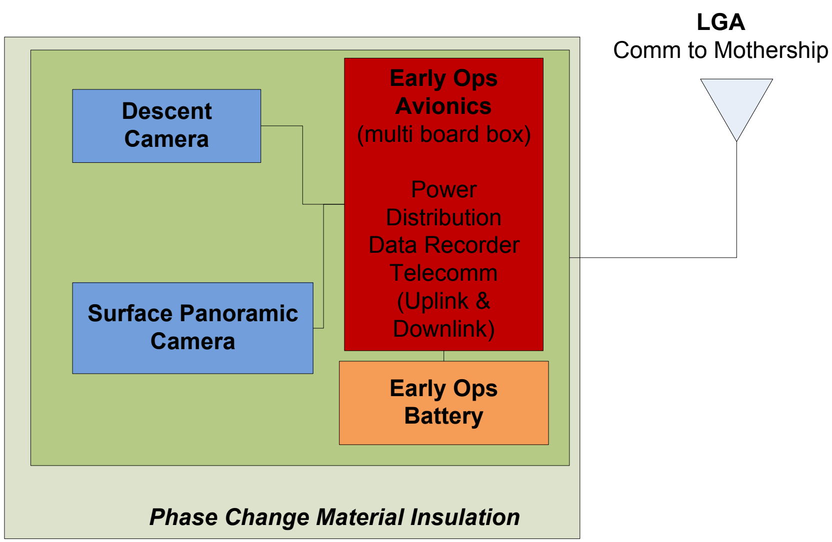
Venus Science and Technology Definition Team, Venus Flagship Mission Study, JPL, April

Venus Flagship Mission Study – Technology Challenges

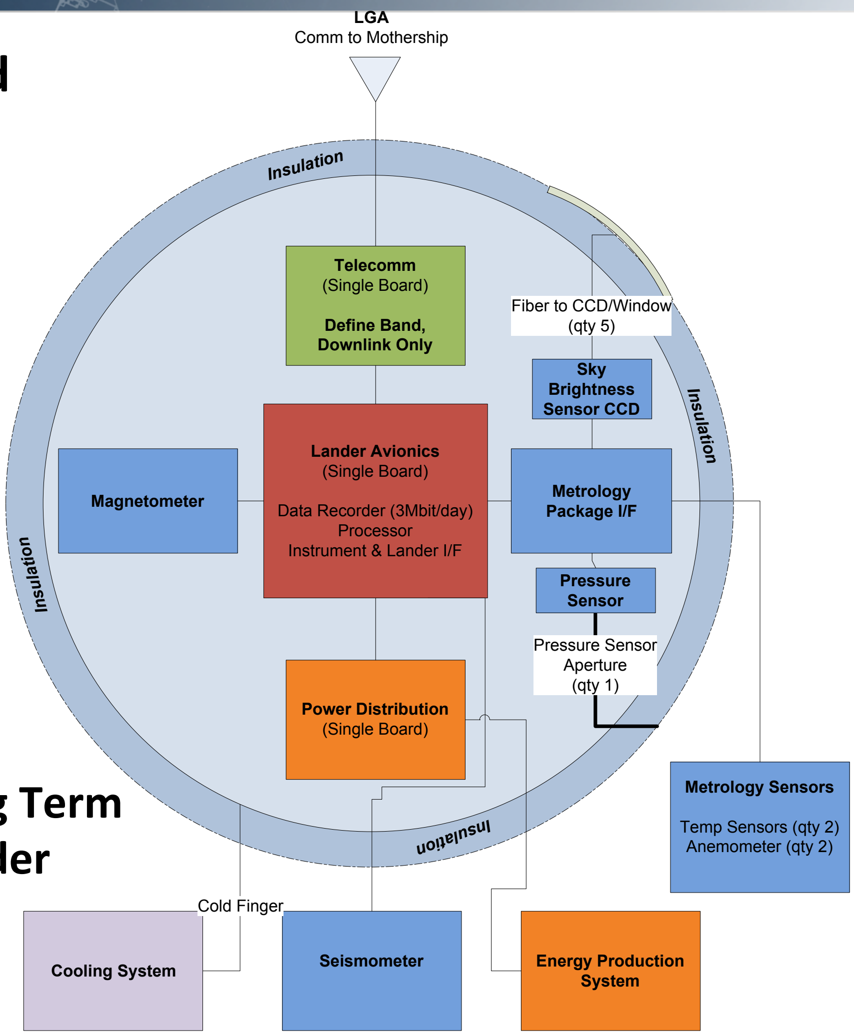
- Two driving technology challenges for the long-lived Lander of the VFM study
  - High Duplex engine operating temperature – 1200C
  - High heat flow from the GPHS bricks to the engine hot end
- The 13,000 W to 23,000 W generated from the GPHS bricks need to be moved from the various bricks to the hot end of the engine, while the hot end of the GPHS pellets is limited to 1335C
  - The needed thermal resistance is about 0.0077 to 0.0044 C/W
- While there is a significant amount of experience with Stirling engines running at 850 C, controlling the material creep at 1200 C is a significant issue
  - The use of the Venus atmospheric pressure to support the pressure differential across the engine is limited because of the effect it would have on the system temperatures and life testing

Venus Pathfinder Mission #1 - Concept

- Lander concept, leveraged off APL asteroid lander study, produces a highly integrated and optimized design that maximizes use of available resources
- Volume is a critical feature of the design

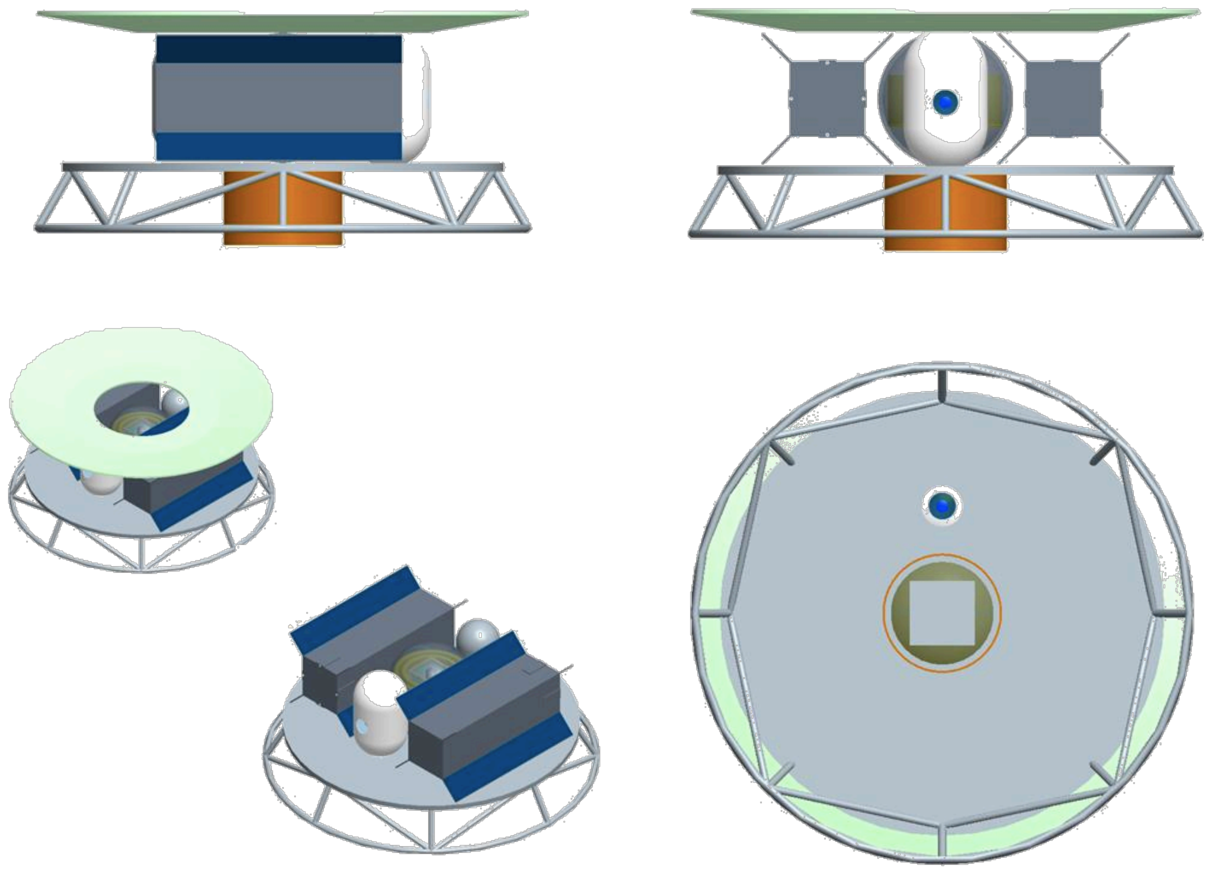


Early Operation, Sacrificial Package



Long Term Lander

Venus Pathfinder Mission #1 – Strawman Configuration



Venus Pathfinder Mission #1 – Concept Description

- Lander concept broken into two distinct packages
  - Long lived package, consisting of power, cooling, instruments and avionics
  - Early operation sacrificial package, consisting of descent and panoramic imagers, battery and avionics
- Segregation of these two packages greatly reduces the cooling requirements on the long lived portion of the lander
  - Less components, smaller volume, fewer feed-thrus
- Long lived package contains primary science package for long-term measurements
  - Small volume enclosure to minimize cooling requirements for long-term mission
  - Designed to reduce overall heat leak into the system
  - External energy production system for long term survival
  - Active temperature control provided by external cooling system
  - Dedicated telecomm system provides data link to mothership or Earth
- Early operation sacrificial package is self-contained system with dedicated telecomm
  - Dedicated telecomm provides both uplink and downlink capability
  - Uplink capability will be used during descent for navigation and ranging
  - Downlink will be used to transmit data from imagers during early operations (0-3 hrs)
  - Passive temperature control via phase change material, providing ~1-3 hrs of protection following landing
  - Power provided by dedicated batteries that will provide 1-3hrs of imager, avionics and telecomm operation

Venus Pathfinder Mission #1 – Early Operation Sacrificial Package

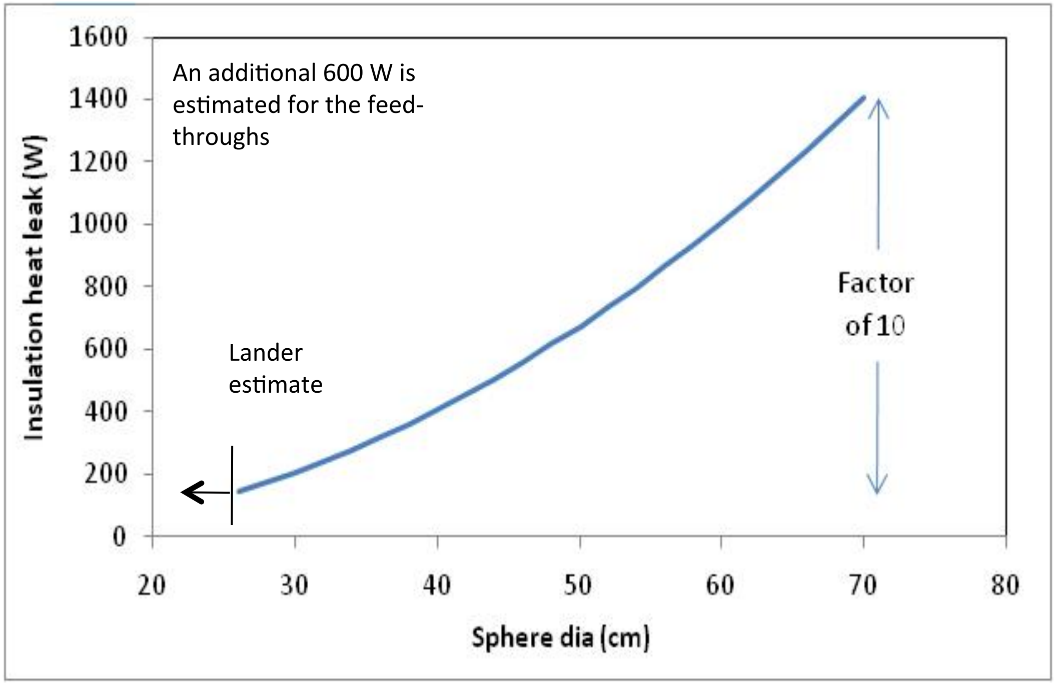
- Separately mounted package that will be used during descent and early operations following landing (1-3hrs)
- Science instrumentation consists of a descent imager and a panoramic imager that only need to survive for a short time following landing
  - Descent imager captures images during descent and documents landing site
  - Panoramic imager will capture views of the landing site from the ground following landing
- Once on surface, images of the horizon are not expected to change over the duration of the mission
  - No need to maintain an imaging package for long term measurements
  - Reduces requirements on the long lived portion of the lander
- Science and housekeeping data will be stored by a dedicated avionics system, separate from the long lived portion of the lander
- Data transmitted back via a dedicated telecomm system and antenna
  - Telecomm system will have both up & down-link capability
  - Will be used during descent to perform navigation and ranging of the probe
- All components in this package will mounted in a vacuum sealed sphere, with passive cooling to ensure 1-3hrs of life following landing
  - Once overheated, systems will no longer operate, and the package will not require any resources from the long lived package

Venus Pathfinder Mission #1 – Long Lived Package

- Consists of three instruments that exploit long duration
  - Magnetometer – internal instrument, enhanced by orbiter magnetometer (if included)
  - Seismometer – external instrument, deployed following landing to decouple from lander
  - Metrology package - including pressure, temperature, wind speed, wind direction and light level
    - Wind speed, direction, temp sensors external instruments
    - Pressure gauge internal instrument with aperture to outside
    - Sky brightness sensors internal instrument with 'widows' thru lander
- Lander avionics, power distribution and telecomm systems all highly integrated, single card systems
  - Allows for a small packaging envelope, reducing power requirements for operation and cooling
- Total power dissipation during normal operations will be ~5-10W total
- All internal components mounted to a dewar-like mounted central structure within a vacuum sealed sphere
- Package requires an external energy and cooling system for long term operations

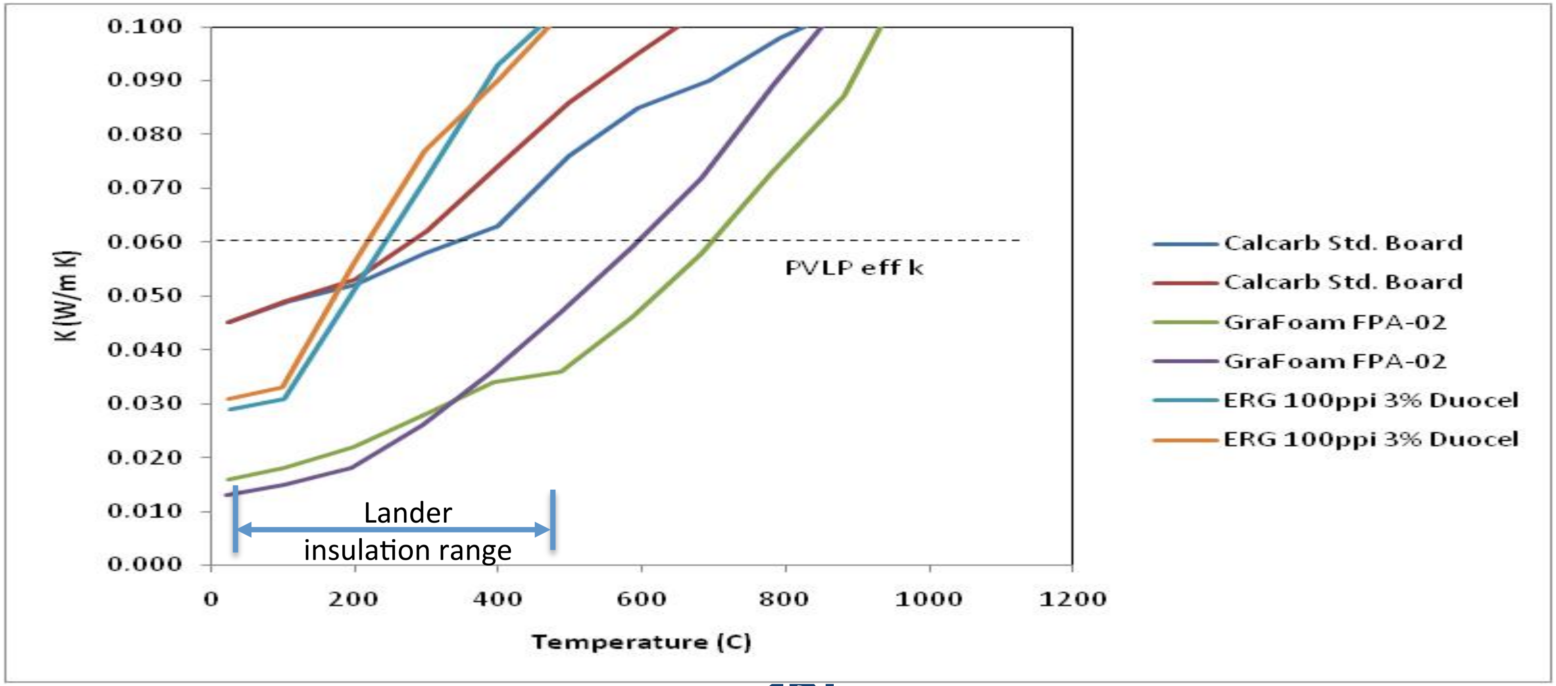
Venus Pathfinder Mission #1 – Cooling Requirements

- **Example: Pioneer Venus Large Probe**
  - Launched May 1978
  - 41 layer MLI blanket, eff k = 0.06 W/m K
  - 72 cm sphere
  - 17 experiments
- **Insulation heat leak**
  - The cooling heat leak includes the area-based, insulation leak and point losses through breaks in the insulation
  - Minimizing these heat leaks is critical to bounding the size and mass of the entire design



Venus Pathfinder Mission #1 – Cooling Requirements

- Controlling heat leaks is critical
  - No apertures are allowed and all harness feed-thrus have long paths and use low thermal-conductivity wire
- Test data of several carbon foam shows there are better insulating materials



Venus Pathfinder Mission #1 – Heat Balance

- A nominal heat balance and design goal are given for the Lander concept

- Lander heat balance

Lander heat balance	Goal	SOA
Internal Power dissipation	5 W	10 W
Insulation heat leak	40 W	70 W
Feed thru het leak	10 W	50 W
Margin	28 W	65 W
Total	83 W	195 W

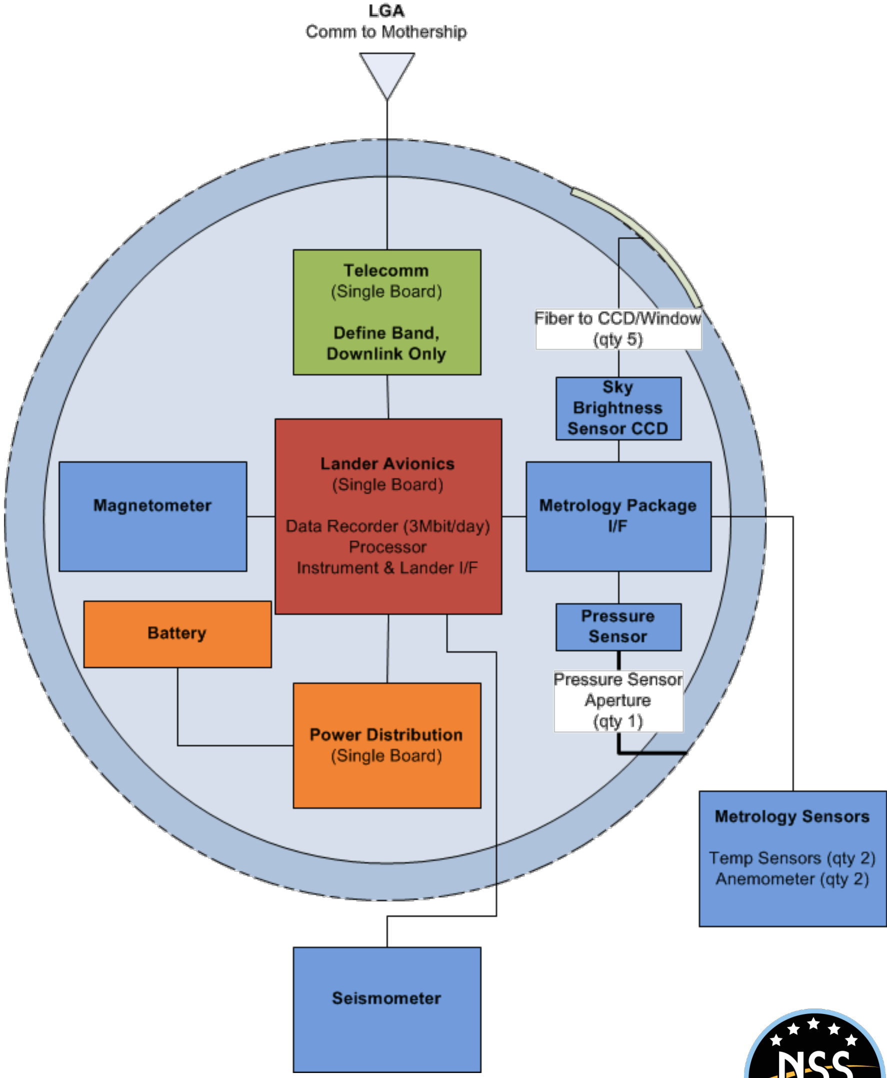
- The power system would need to be designed to provide at least 200 W
  - The number of GPHS bricks is estimated to be about 8

Venus Pathfinder Mission #1 – Technology Challenges

- The Pathfinder #1 design can take advantage of technology plan at NASA GRC
  - Stirling Duplex System operating at near-normal hot end temperatures is much closer to being demonstrated
  - There is active high-temperature sensors development underway supporting in situ engine diagnostics
  - The new Venus environment chamber allows realistic life-testing
- These capabilities may be short-lived as the priorities from other programs and the recommendation of the 2011 Decadal Survey are assessed

Venus Pathfinder Mission #2

- Architecture elements
  - Orbiter Relay
  - Entry system
- Long-Lived Lander
  - 15 days, across sunrise (or sunset)
  - Power 1 We payload, ambient temperature operation
  - Battery sizing 470 W-hrs
  - Data processing in orbiter
- Target landing zone
  - +/- 7.5 degrees (vary as cosine of latitude)
  - Lower latitude preferred to maximize sunlight
  - Combining dawn/dusk time, entry angle constraints, and geological sites may be difficult



Venus Pathfinder Mission #2 - Technology Challenges

- The Pathfinder #2 design needs a directed technology plan to develop a high temperature system
  - The need for high temperature electronics, as opposed to sensors, requires experience with data handling and calibration
  - High temperature batteries have to be optimized for the Venus environment and demonstrate their long term performance at temperature
- In the longer term, the high temperature system, if developed, will probably offer more mission options

Conclusions

- There are a range of different technologies that support different types of missions.
- The large power and cooling needs of the VFM-type mission requires an ambitious technology plan and a multiple year commitment
  - Ultimately, it provides the largest return
- A mission approach combining a short term lander with a long term seismicity/meteorology package provides compelling science with a simpler technology development plan that is achievable sooner
  - It probably has shortest developmental timeline
- A shorter term mission, potentially including one or more smaller, high-temperature landers would be the simplest overall system
  - A longer term technology development plan is needed

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